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ON-POWER CONTAINMENT LEAKAGE TESTS AT NPD

Report No. 87-8-K

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ABSTRACT

On-going tests at NPD have provided an opportunity to investigate a tracer gas technique for on-power leakage rate determination thereby identifying sectors in which leak site searches should be concentrated. The sectors investigated included the boiler room, the fuelling machine room, the vault cooling room and an excavated area adjacent to the vault. Leakage rates to the vault were measured using sulphur hexafluoride and were each approximately 10% of the total for the fuelling machine room and the boiler room. The leakage rate for the excavated area was found to be significantly higher at 30% of the total. However, 50% of the total leakage was elsewhere. The use of SF_6 for on-power measurements has been demonstrated. Helium is the preferred tracer gas if background levels are low and relatively constant and further evaluation of it and ethylene through in-station testing is recommended.

job	file	date	report no
31-131-550	835.6212	March 12, 1987	87-8-K

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EXECUTIVE SUMMARY

ON-POWER CONTAINMENT LEAKAGE TESTS AT NPD

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Control of leakage at Nuclear Generating Stations (NGS) is desirable to minimize emissions of radionuclides. The main technique used currently for leak site identification and leak quantification in NGS is air pressurization of the containment envelope with the reactor off-power. Soap solution is used to check known penetrations but is labor intensive and does not cover the entire containment boundary. A tracer gas technique has been used during an off-power, pressurization test at Bruce NGS and was successful in identifying a sector having significant leakage and a leak from an unexpected source. However, this tracer technique also shows potential for on-power use. Sectors adjacent to the reactor vault having significant leakage may be identified through measurement of leakage rates to the vault while the station is producing power under the normal operating pressure differentials. On-going leakage tests at NPD provided an opportunity for demonstrating the technique in the field and identifying sectors in which leak site searches should be concentrated.

A total of five tests were performed at NPD. The sectors investigated were the fuelling machine room, the boiler room, an excavated area near the east wall of the reactor vault, the vault cooling room and a motorized valve installed in a vault purge duct leading to the stack. Several tracer gases (sulphur hexafluoride, ethylene and helium) were used. This was because there was insufficient time in between tests to clear the area of tracer gas used in the previous test. Also, it provided an opportunity for comparing the relative ease of injecting and measuring the different gases under field conditions. Generally, the tests consisted of injecting tracer gas of the desired quantity into a sector and then measuring the vault concentration while maintaining a constant injection area concentration. Leakage rates were obtained from mass balances.

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On-power leakage rate measurement from selected areas adjacent to containment was demonstrated using SF_6 as the tracer gas. The leakage rates from the fuelling machine room and the boiler room to the reactor vault were each about 10% of the total and from the vault cooling room less than 5%. However, a helium test on the excavated area which was of low accuracy because of high background helium concentrations in the reactor vault showed that the leak could be about 30% of the total and a repeat of this test with sulphur hexafluoride is recommended. Motorized valve MV22 was found to leak at a negligible rate. The data suggest that 50% of the total leakage is elsewhere.

Helium is the preferred tracer gas for on-power leakage rate measurements if background levels are low and relatively constant. However, use of the method in multi-unit stations requires restricting loss of tracer gas along the fuelling machine duct and an investigation of this is recommended. Ethylene as a tracer gas has the advantage that measuring equipment is inexpensive so that several searches can be carried out simultaneously and rapidly. Also, the equipment is simple to set up and operate and detecting at significant distances away from a leak is possible. Further evaluation of ethylene and helium through in-station testing is recommended.

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To Mr. R.E. Lewis
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ON-POWER CONTAINMENT LEAKAGE TESTS AT NPD

1.0 BACKGROUND

Emissions of radionuclides (tritium, iodine, etc) to the external atmosphere during normal operation of Ontario Hydro's Nuclear Generating Stations (NGS) can be minimized to even below the presently acceptable operating levels if the leakage of the containment area around the reactor is reduced to as low values as possible. This reduction in leakage may be accomplished by locating and sealing of leak sites and not by reducing the required pressure differential between the containment area and the surrounding in-station atmosphere since back diffusion to the station atmosphere can occur. However, more importantly minimization of leakage is desirable in the event of a loss of coolant accident when high pressure differences may exist. In the case of NPD during normal operation low leakage is desirable to avoid release of Argon-41 formed in the ventilated annulus between pressure and calandria tubes.

The current method for leak site identification and leak quantification is mainly air pressurization of the containment envelope with the reactor off-power. The major technique in use is to spray soap solution at known penetrations but the disadvantage of this technique is that it is labor intensive and leaks occurring away from locations tested will not be found. A tracer gas technique has been demonstrated at Bruce NGS during the off-power commissioning stage with the containment pressurized/1/. Its major advantage was the ability to indicate leaks from unexpected sources. However, this technique may also be suitable for determining leakage rates to containment from selected areas adjacent to containment while the reactor is producing power. Leak site searches would then be concentrated on areas showing significant leaks. On-going tests at NPD offered an opportunity for its development and several tests were carried out as requested by NPD. Time limitations which prevented the complete purge of tracer gas from the work area indicated the desirability of using more than one tracer gas and experience was obtained with sulphur hexafluoride, helium and ethylene.

2.0 DESCRIPTION OF TESTS

A total of five tests were performed (Table 1). The fuelling machine room to the vault leakage rate was first tested because of the possibility of leakage at the fuelling machine gate seals and purging of

TABLE 1 Details of Tracer Gas Test Conditions

Test Number	Date and Time	Tracer Gas Used	Injection Point	Injection Amount	Locations Sampled
1 Fuelling Machine To Vault Leakage	Wed 15th Oct 1986 14:30 to 16:00 h	Sulphur Hexafluoride (SF_6)	FM-TM-V1 South wall of Fuelling Machine Room	5L/min* for 2 min	FM air drawn from V1 and injection line, also vault air from valve V36 in vault cooling circuit
2 Boiler Room to Vault Leakage	Thurs 16th Oct 1986 10:30 to 19:00 h	Sulphur Hexafluoride (SF_6)	V-108, Drawing 735HNI; Boiler Room Ventilation Drying Circuit	5L/min for 10 min at 10:30 h; 5 L/min for 1 min at 16:30 h	Same as injection point, also valve V36 for vault air sampling
3 Vault East Wall Leakage	Thurs 16th Oct 1986 16:30 to 19:00 h	Helium (He)	Through hatch into excavated area below ventilation service space	7000 L in 35 min	Vault air through V36
4 Vault Cooling Room to Fuelling Machine Room Leakage; VCR Duct/Fan Seal Leakage	Fri 11th Oct 1986 09:15 to 11:00 h	Ethylene (C_2H_4)	Through line running into Vault Cooling Room & the door sealed with tape	6.6L/min for 17 min at 9:30 and for 5.5 min at 9.54	Fuelling machine Room through V1; Vault through V36
5 Vault Purge Valve Leakage	Fri 17th Oct 1986 11:30 to 13:10 h	Sulphur Hexafluoride (SF_6)	3/8" Swagelok installed down stream of MV22 (Drawing 734 HNI)	1L/min for 30 min	Vault Air through V36

*Litres measured at 25°C, 101 kPa

the tracer gas from the room could be done relatively quickly. Similarly, the boiler room to vault leakage rate was next investigated since the labyrinth seals at the feeder pipes were suspect. The third test concentrated on whether leaks were present from an excavated space in the area of the tube withdrawal room and the east wall of the reactor vault through seams/joints in the concrete walls. The fourth test investigated the presence of leakage from the vault cooling room to the fuelling machine room through similar concrete imperfections. In this test, the vault air was also sampled because of the possibility of leakage of ducting upstream of the vault air circulation fan and the fan seals. Finally, a normally closed motorized valve used for vault purging prior to maintenance was tested for approximate leakage rate. This motorized valve is in a line leading to the stack and any leakage would allow ventilation air normally sent to the stack to reverse flow back into the reactor vault through the vault cooling system.

3.0 EXPERIMENTAL EQUIPMENT AND PROCEDURE

Details of the experimental equipment and procedure are given in Appendix A. Generally, the tests consisted of injecting tracer gas of the desired quantity into a given room and then determining its presence in the reactor vault. If leakage rates were desired, the concentration was maintained approximately constant in the injection area and the vault concentration was monitored until it was constant. This was a variation of a previously proposed procedure/2/ in which tracer gas was injected into containment and simultaneously measured in adjacent rooms which had their pressures reduced. However, if the technique used here is to be useful at multi-unit stations such as Bruce NGS, it will be necessary to investigate methods of reducing tracer gas loss to other units along the fuelling machine duct eg, a temporary plastic sheet barrier may be adequate.

A discussion on tracer gas properties is presented in Appendix B.

4.0 RESULTS AND DISCUSSION

4.1 Fuelling Machine Room to Reactor Vault Leakage Rate

As shown in Table 1, SF_6 was injected into the FM room at 5 L/min for two minutes. For a 566 m^3 FM room volume the average concentration of SF_6 is calculated to be 19 μL/L This concentration is in good agreement with that of 20 μL/L determined by the infrared analyzer. In this test, a steady state vault concentration was quickly reached within 75 minutes (see Appendix E) probably because during injection the SF_6 gas cloud initially sank to the floor area near to the fuelling machine gates before becoming uniformly mixed over the entire volume. This latter was shown by the constant SF_6 concentration in the FM room after 30 minutes had elapsed from the start of injection. This is an acceptable mixing time considering the room was not ventilated nor were fans introduced. About one hour after the injection the vault concentration was 2.0 μL/L

and it remained constant thereafter. Also, because the FM room had restricted ventilation, the SF_6 concentration remained essentially constant. Assuming no adsorption of SF_6 by the vault molecular sieve dryers (Appendix C), a mass balance yields:

FM Room to Reactor Vault Leakage rate (L/s) x Fuelling Machine Room Concentration (μL/L)

= Reactor Vault Exhaust Rate (L/s) x Reactor Vault Conc (μL/L)

(Eq. 1)

Recorded data from station instrumentation showed that the reactor exhaust flow was 16 L/s (vault pressure -17 Pa(g)) during the test. Hence, the FM room to reactor vault leakage rate was 1.6 L/s or 10% of the total. Note that the higher the concentration attained in the reactor vault, the larger is the leak from the room under test (Equation 1).

At the end of the test, the atmosphere of the fuelling machine room was dried by a boiler room drier (VDR-1). This allowed a small amount of ~0.1 μL/L of tracer gas into the boiler room the next morning when the boiler room leakage was tested. Following the drying of the FM room, ventilation air was allowed to flow through it to purge it of residual tracer gas thereby avoiding interferences with subsequent tests. Note, however, that the time to reduce the reactor vault concentration to one-half of its initial value would be about 4 hours for an exhaust flow of 16 L/s and a reactor vault volume of 340 m^3 (see Equation 2 below).

Hence, about 24 hours would be required to reduce the vault concentration to 1.5% of its initial value to avoid gross interference with subsequent tests. Increasing the vault exhaust rate to 38 L/s (see below) would require 10 hours for a similar decrease in concentration and this was attempted. Note also that the time required to reduce the concentration is directly proportional to the volume of the vault.

4.2 Boiler Room to Reactor Vault Leakage Rate

As shown in Figure 1, SF_6 was first injected into the boiler room at 10:40 hours. The observed SF_6 concentration near the start of the test was 18 μL/L. This showed good initial mixing since this value is close to 19 μL/L calculated from the amount (50 L) of SF_6 injected and the volume of the boiler room (2633 m^3). Near the start of the test, the SF_6 concentration in the reactor vault was 0.8 μL/L down from 2 μL/L measured the previous afternoon. This reduction was obtained after drying the FM room then purging it to remove SF_6 and with the vault exhaust rate increased to about 38 L/s overnight. This residual concentration was greater than expected because of the significant time required to dry and purge the FM room. Following the first SF_6 injection, the concentration in the reactor vault increased while the

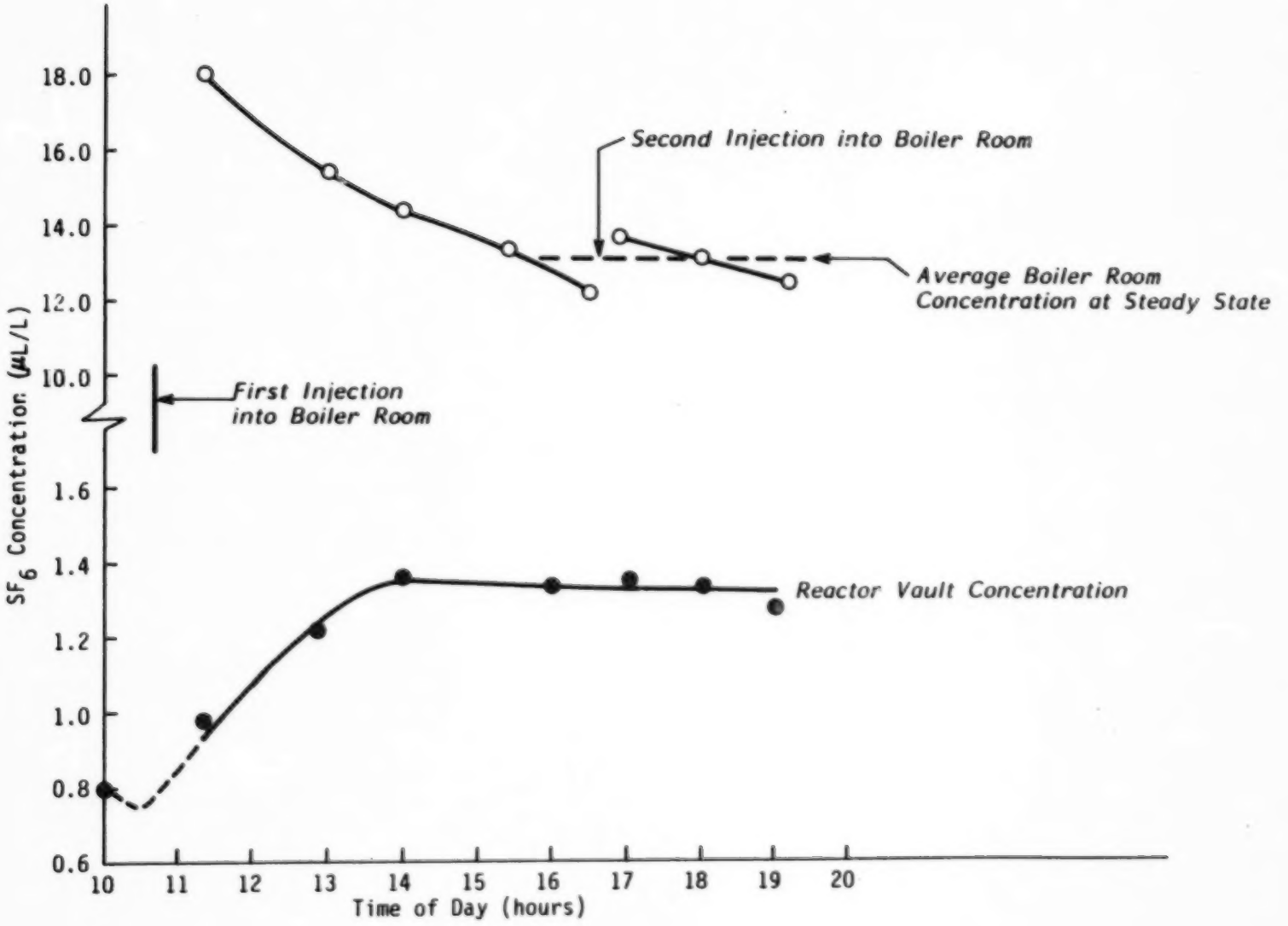

FIGURE 1

BOILER ROOM AND REACTOR VAULT CONCENTRATIONS
DURING BOILER ROOM LEAKAGE TEST

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boiler room concentration decreased.

A mass balance over the boiler room yields:

$$\int_{[SF_6]_{initial}}^{[SF_6]_{final}} \left[-\ln [SF_6] \right] = \frac{\text{Boiler Room Exhaust Rate}}{\text{Boiler Room Volume}} \times \text{Time} \quad \text{(Eq.2)}$$

Substituting a $[SF_6]_{initial}$ of 18 μL/L at 11:20 hours, a $[SF_6]_{final}$ of 12.25 μL/L at 16:30 h gives a boiler room exhaust rate of 54 L/s. Since the boiler room to reactor vault leakage rate was about 2 L/s (see below) the net boiler exhaust rate becomes 52 L/s. This compares favorably (~15%) with the 45 L/s flow rate indicated by station instrumentation during the test. The loss rate is on the high side probably because of adsorption on the 13X molecular sieve in the boiler room dryers (see Appendix C). The reasonable agreement is a demonstration of the feasibility of the tracer technique.

At steady state (~6 hours after the first injection) the boiler room concentration was 13.2 μL/L while the reactor vault concentration was 1.32 μL/L. Hence, the boiler room to vault leakage may be found by a mass balance similar to that described by Equation 1. Recorded data from station instrumentation showed that the reactor vault exhaust flow was about 16 L/s. Hence, the boiler room to reactor vault leakage rate was 1.6 L/s or 10% of the total. During this period, the reactor vault pressure was -17 Pa(g) and the boiler room pressure was about -7 Pa(g).

4.3 Excavated Area Leakage

This area was tested with helium because it is not normally ventilated and tracer gas removal after the test would be aided by the faster diffusion of helium. Also, a different tracer gas was required since the boiler room leakage test with SF_6 was underway. As shown in Figure 2, the concentration of helium in the reactor vault was high at 14.00 hours due to purge of the moderator cover gas. Purging was discontinued and the helium concentration decreased until 16:00 hours. At this time a brief moderator purge occurred resulting in an increase in helium concentration to above 1.2 volume percent. Helium injection was then carried out between 16:38 and 17:13 ie, for thirty five minutes during which about 7000 L of helium was added to the excavated area. For an estimated excavated volume of 500 m^3, the helium concentration there is calculated to be 1.4%. From Figure 2, at a vault helium concentration of 1.2%, the rate of decrease of the vault helium concentration after injection into the excavated area was 0.07% per hour. This is significantly less than the rate before helium injection (0.14% per hour). A mass balance on the helium entering and leaving the reactor vault (pressure = -17 Pa(g)) indicates a leakage rate of about

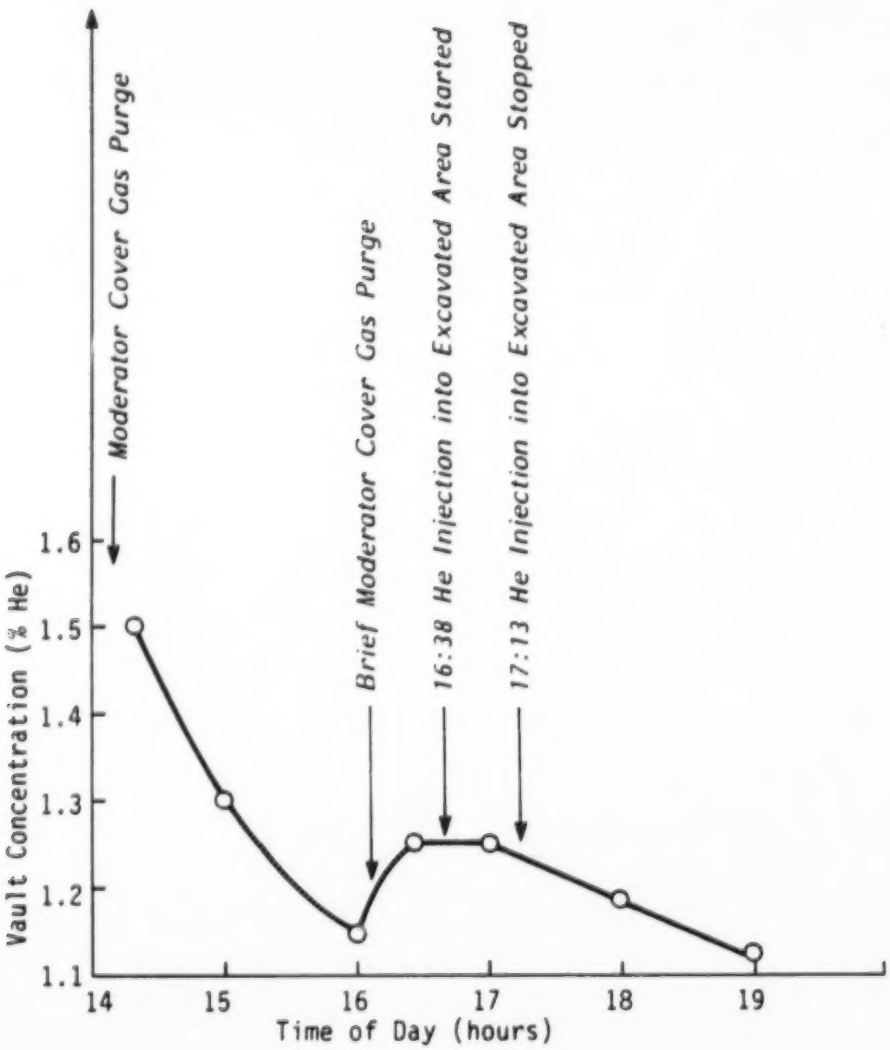

FIGURE 2

VAULT HELIUM CONCENTRATION DURING EXCAVATED AREA LEAK TEST

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5 L/s. However, the error could be significant because the changes observed in the measured concentrations were small with the actual concentrations being relatively large. It is recommended that this area be visually inspected and re-tested with SF_6.

4.4 Vault Cooling Room Leakage Test

This test was of limited duration because Fuelling Room maintenance was scheduled. Also, it was not possible to shut off the ventilation flow (1130 L/s) in the vault cooling room (VCR) during this test because of the possibility of significant heating of the room atmosphere and high radiation fields. Ethylene was injected at about 6.6 L/min into the VCR (volume = 255 m^3) commencing at 9:13 for seventeen minutes. The exit of the ethylene injection tube was placed directly in front of a fan allowing rapid dispersion of the ethylene below the lower explosion limit of 3.5%. Samples of the fuelling machine room and the reactor vault atmospheres were taken at 9:38 and analyzed by Matheson-Kitagawa tubes. No ethylene was detected in either sample (the lower detection limit of the tubes claimed by the manufacturer was 0.1 μL/L and limited tests at Ontario Hydro Research Division confirmed this).

An estimate of the lowest leakage rate that might be detected under the above conditions is given in Appendix F. The leakages from the vault cooling room to the fuelling machine room and the reactor vault are calculated to be less than 0.6 L/s and 0.8 L/s, respectively.

4.5 Motorized Valve (MV22) Leakage Tests

In this test, SF_6 was injected at 1 L/min for twenty minutes into the ducting of MV22 leading to the stack. Only one vault recirculation fan was running (vault pressure -20 Pa(g)). After twenty minutes, injection was continued at the same rate for a further twelve minutes but with the second vault recirculation fan on. Injection was shut off after a total of thirty-two minutes but monitoring of the vault concentration continued. The SF_6 concentration in the vault during this test is shown in Figure 3. Note that at the start of injection there was a significant amount of residual SF_6 in the vault from the previous day's testing. However, the increase in vault concentration indicated that MV22 was allowing ventilation air which would normally be sent to the stack to leak back into the reactor vault. As shown in Figure 3, switching on a second fan had no significant effect on the leakage rate suggesting that the difference between the vault pressure and stack ducting pressure was the main driving force for leakage.

An approximate analysis given in Appendix G estimates the leakage rate to be less than 0.1 L/s and insignificant compared to the total vault exhaust rate of about 16 L/s.

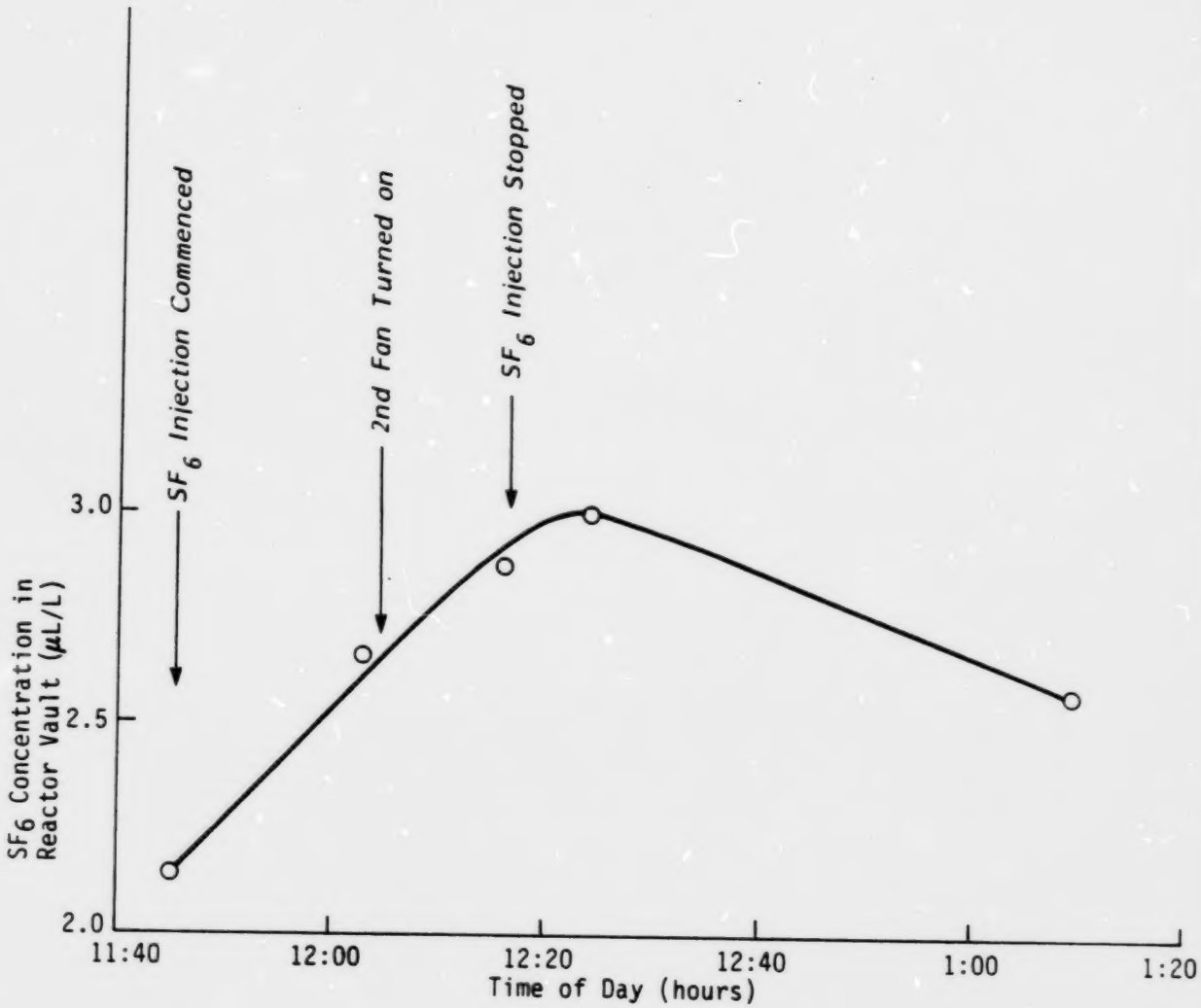

FIGURE 3

TRACER GAS CONCENTRATION IN CONTAINMENT DURING MV22 TEST

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5.0 CONCLUSIONS AND RECOMMENDATIONS

1. On-power leakage rate measurements from selected areas adjacent to containment using SF_6 tracer gas is feasible at NPD. An accuracy of about 15% is expected.

2. The leakage rate from the NPD fuelling machine room to the reactor vault (pressure -17 Pa(g)) was about 1.6 L/s. A similar rate (1.6 L/s) was found for the boiler room to vault leakage. Leakage, if any, from the vault cooling room to the reactor vault was less than 0.8 L/S. The data for leakage from the excavated area to the reactor vault suggest a rate of about 5 L/s. It is recommended that this area be visually inspected and re-tested with sulphur hexafluoride tracer. Motorized valve MV22 leaked air that would normally go to the stack back into the reactor vault. However, the leakage rate was estimated to be less than 0.1 L/s under normal operating pressure differentials.

3. The total of all leakages found accounts for about 50% of the total which was 16 L/s. This suggest that leakages exist elsewhere, eg, process equipment, sample lines, inaccessible areas etc.

4. Helium is the preferred tracer gas for on-power leakage rate measurements if (i) the background concentration is not excessively large such that very large concentrations in the injection area are required to provide adequate accuracy and (ii) the background concentration does not fluctuate greatly. Tests to prove the feasibility of on-power leakage rate with helium tracer gas should be carried out at NGS where background concentrations are low. Also an investigation of methods of reducing tracer gas loss along the fuelling machine ducts will probably be necessary for multi-unit stations.

5. Unlike methane, ethylene is an attractive tracer gas because suitable measuring equipment is relatively inexpensive and simple to set up and operate by unskilled personnel. Also, high dilution ratios are available allowing leak detection at distances similar to those obtained with SF_6 for pressurization tests. The major disadvantage of ethylene is that the analysis time may be long (ten minutes for 0.1 μL/L concentration reducing to two minutes for 0.5 μL/L). Also, precautions are necessary to prevent explosive concentrations during injection, in dryer regeneration circuits and in water tanks if dissolution and subsequent desorption occurs. Further evaluation of ethylene as a tracer gas through in-station tests is recommended.

6. Very little SF_6 is adsorbed by AW500 sieve but significant adsorption is exhibited by dry 13X molecular sieve. The adsorption of SF_6 by sieve which is almost saturated with water is very small. The possibility of SF_6 breakdown during dryer regeneration may be avoided if the dryers are run to full capacity with water.

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APPENDIX A

Experimental Equipment and Procedure

A.1 Sulphur Hexafluoride Tests - Fuelling Machine Room, Boiler Room, MV22

The equipment used for injecting the SF_6 tracer gas and sampling the areas (normally two at any given time) under study is shown in Figure A.1. All lines were made of 0.63 cm polyethylene tubing and stainless steel fittings which were available. Typically, a test was carried out by injecting tracer gas at a calibrated known rate for the desired time with the unshaded valves open (Figure A.1). The injection line was then flushed of tracer gas into the injection area with zero air for two minutes. The reactor vault was then sampled (undesirable traces of SF_6 were found in the sampled gas because of incomplete flushing of the dead legs near the selection valves but the readings rapidly fell and then approached the steady state value; separation of injection and sampling systems in future tests will overcome this problem and allow sampling during the injection period). The valve at the exit of the infrared analyzer was closed and the pump stopped allowing the pressure in the infrared analyzer to rise to atmosphere levels at which the analyzer is normally calibrated. Measurements were then repeated until steady state conditions were obtained. During the measurement of the leakage from the boiler room to the reactor vault, it was necessary to add SF_6 to the boiler room once late in the test to compensate for the loss through the boiler exhaust flow and to maintain a constant concentration. Precautions were also taken to direct all sampled gases to the ducting of the ventilation system from which they were carried to the stack.

A.2 Ethylene Test - Vault Cooling Room

The injection equipment for the test carried out with ethylene was similar. It consisted of a cylinder (4.54 kg total), a pressure regulator, a mass flow meter, and a 0.63 cm diameter polyethylene line leading to the vault cooling room. The door of this room was slightly ajar allowing passage of the tube and the opening around the perimeter of the door was sealed with cloth tape. Analysis of the ethylene was carried out by collection of gas samples in 5L Tedlar (polyvinyl fluoride) bags and performing detector tube (Drager and Matheson-Kitagawa) determinations in the chemistry laboratory fume hood. Limited tests on the Matheson-Kitagawa tubes at Research Division showed no deviation from the manufacturers claims on accuracy and lower detection limit (0.1 μL/L). However, a disadvantage of the method is that the analysis is time consuming at low concentrations requiring ten minutes per sample for five pump strokes.

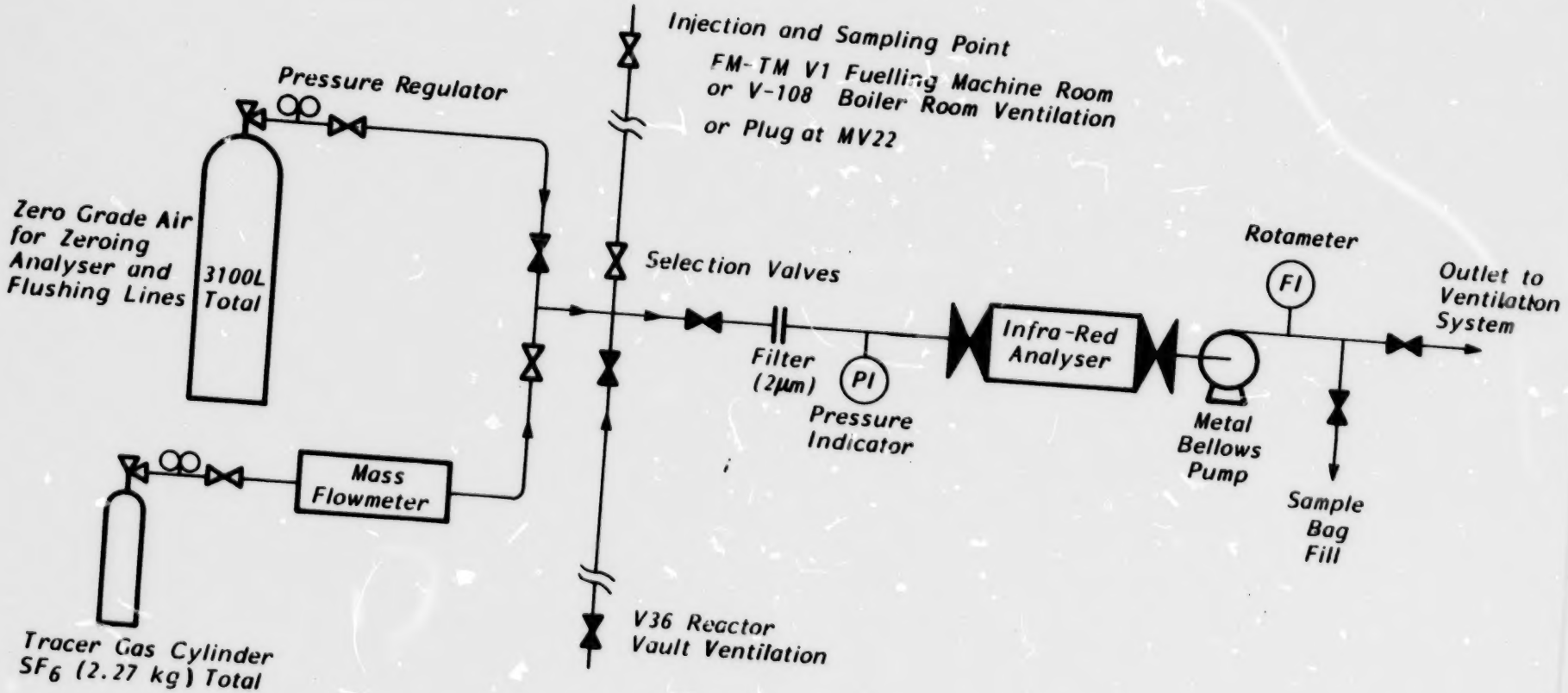

FIGURE A.1

INJECTION, SAMPLING AND ANALYSIS EQUIPMENT FOR SULPHUR HEXAFLUORIDE

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A.3 Helium Test - Excavated Area

Helium injection was carried out using a 7500 L total capacity helium cylinder equipped with a pressure regulator set at about 350 kPa. A line of 0.63 cm polyethylene was passed for about seven metres into the excavated area below the ventilation service space. The line passed through a gap between the lifting lug and the hatch cover which was then sealed with cloth tape. Analysis of helium was carried out by bag sampling and with a Gow-Mac Leak Detector Model 21-150, operating on a thermal conductivity principle (sensitivity: 7 μL/L He gives a reading of 1 on the high sensitivity scale). The detector was calibrated with known concentrations of helium.

APPENDIX B

Tracer Gas Properties

B.1 Sulphur Hexafluoride

Sulphur hexafluoride is a good tracer gas since in addition to other desirable properties (eg, low cost), low concentrations can be accurately and continuously determined by infrared (IR) analysis. The absorption wave length used avoids interference by changing concentration of H_2O, D_2O and CO_2 normally present in air. For example, it would require a 4000 μL/L D_2O concentration change to produce a 0.1 μL/L error in the SF_6 concentration determination.

However, a major disadvantage is that breakdown to corrosive fluoride compounds can occur at high temperature and in the presence of water and in the radiation field of a nuclear reactor. Evaluation of its use at NPD indicated no concern with respect to corrosive effects/3/ and breakdown products (Appendix D) on reactor components. A minor disadvantage of analysis by IR is the necessity of providing suitable SF_6 free gas for zeroing the instrument. Also, corrections for the operating pressure at the analyzer being different from the pressure (atmospheric) at which the analyzer is calibrated are necessary. Otherwise, the sampling pump must be stopped and the pressure at the instrument allowed to increase to atmospheric before readings are taken. Finally, if large quantities of SF_6 are present, dryers with 13X desiccant should be run to full breakthrough ie, saturation with water to remove adsorbed SF_6 which might breakdown during the regeneration cycle.

B.2 Ethylene and Methane

The use of ethylene as a tracer gas has the advantages that the measuring equipment is relatively inexpensive so that several searches can be ongoing simultaneously. The equipment is simple to set-up and easy to operate. Also background concentrations are usually negligible. Unlike the Miran infrared analyzer, zeroing which requires time and an appropriate gas supply is not required nor is the operation complicated by the need to match operating and calibration pressures or to correct readings for different operating and calibration pressures. A dilution ratio as large as 10000 (1000 μL/L in containment + 0.1 μL/L lower detection limit of tube) is available which is similar to that obtained with SF_6 and allows detection at practical distances away from significant leaks. Tubes are also reusable if no discoloration occurs and this reduces costs.

A precaution to be observed with ethylene as a tracer gas is that concentrations in dryer circuits must be limited to prevent explosive

concentrations during regeneration of the dryer unless the dryer is run to full breakthrough (saturation capacity).

Also, the injection system should be designed that the ethylene issuing from the injection line is immediately diluted with a gas stream from a fan to ensure that the concentration does not exceed the lower explosion limit. Otherwise, dilution in the injection line can be carried out.

Because of the detector tube low accuracy (68% of all readings using a single tube will be within about 25% of the true value) leakage rate measurements will not be as precise as for SF_6 unless the determination is carried out by averaging the indication of several tubes. Therefore, the analysis may be time consuming as five strokes of the pump required for the analysis takes ten minutes if concentrations as low as 0.1 μL/L are being investigated; this reduces to two minutes for 0.5 μL/L. Finally, the higher solubility of ethylene may be a disadvantage if open water surfaces are present. For example, although the dissolved ethylene (1000 μL/L air concentration) would be only 2% of the dissolved oxygen at 25°C, it is three orders of magnitude greater than dissolved SF_6 (air concentration 100 μL/L).

It is not expected that any permanent damage to charcoal in the iodine filters will occur since ethylene will elute as in a gas chromatographic column. Also, the extent to which elemental I-131 will be emitted is expected to be small since displaced iodine will subsequently react with ethylene and the product trapped by the triethylene diamine impregnant on the charcoal. Nitrogen dioxide is not expected to be a problem since no discoloration was obtained using vault air at NPD.

Methane was initially considered as a tracer gas for the vault cooling room leakage test. However, ethylene was used since the infrared analyzer sensitivity for methane was about 10 μL/L. Also, there is significant interference by H_2O at the analytical wavelength. While removal of H_2O during testing by Drierite may be possible, it adds to the complexity of the measuring apparatus.

B.3 Helium

The test on the excavated area shows that helium may be used as a tracer even if background levels are high (~10,000 μL/L) or the concentration is steadily decreasing. However, under these conditions, significantly higher helium concentrations must be injected into the room being leak tested for the accuracy of the determination to be acceptable and this results in increases costs. Nevertheless, the helium injection was the easiest to prepare for and carry out as compared to SF_6 and ethylene. Only one analyzer is required for leakage rate measurements on individual sectors.

APPENDIX C

Adsorption of Sulphur Hexafluoride on Molecular Sieve

Use of SF_6 tracer gas in the reactor vault and boiler room may result in adsorption of SF_6 on the reactor vault dryer desiccant (type AW500 molecular sieve) and the boiler room dryer desiccant (13X). This adsorption is undesirable because it may require intermittent SF_6 addition to the area under study in order to maintain a constant concentration for leak rate determination. Also, this SF_6 could breakdown to corrosive products during regeneration. Hence, tests were carried out on the adsorption capacity of AW500 and 13X molecular sieve for SF_6.

C.1 Method

The measuring system consisted of a closed loop made up by the infrared analyzer, a metal bellows pump and a 150 mL stainless steel molecular sieve container. Following calibration of the analyzer, known amounts of SF_6 were injected into the circulating loop, the volume of which was also known.

The analyzer gave the SF_6 volume in the gas phase. The difference between the volume injected and the volume in the gas phase was the adsorbed volume. Additional amounts of SF_6 were added to increase the gas phase composition allowing additional data points on the adsorption isotherm (SF_6 concentration in gas phase vs SF_6 concentration on sieve at constant temperature).

C.2 Adsorption of SF_6 on AW500 Molecular Sieve

Infrared analyser absorbance measurements in the SF_6 concentration range of 0.5 to 20 μL/L showed no significant change if dry Linde AW500 sieve pellets (1/8", 21g sample) were present or not. An estimate based on the slope of the calibration curve (SF_6 conc vs absorbance) and the readability of the meter scale indicates that the capacity of AW500 for SF_6 was less than 0.2 μL/g at 20 μL/L SF_6 and less than 0.002 μL/g at a 0.5 μL/L SF_6 concentration. This low capacity is expected since the Lennard-Jones kinetic diameter/4/ of SF_6 is 5.5 Angstroms while the effective pore size of the AW500 is about 4 Angstroms. Because of similar pore size, 4A sieve is expected to behave similarly to AW500 sieve.

C.3 Adsorption of SF_6 on 13X Molecular Sieve

Adsorption data for SF_6 on Linde 13X pellets (1/8", 74 g sample) are presented in Figure C.1. At a 20 μL/L SF_6 concentration, adsorption of

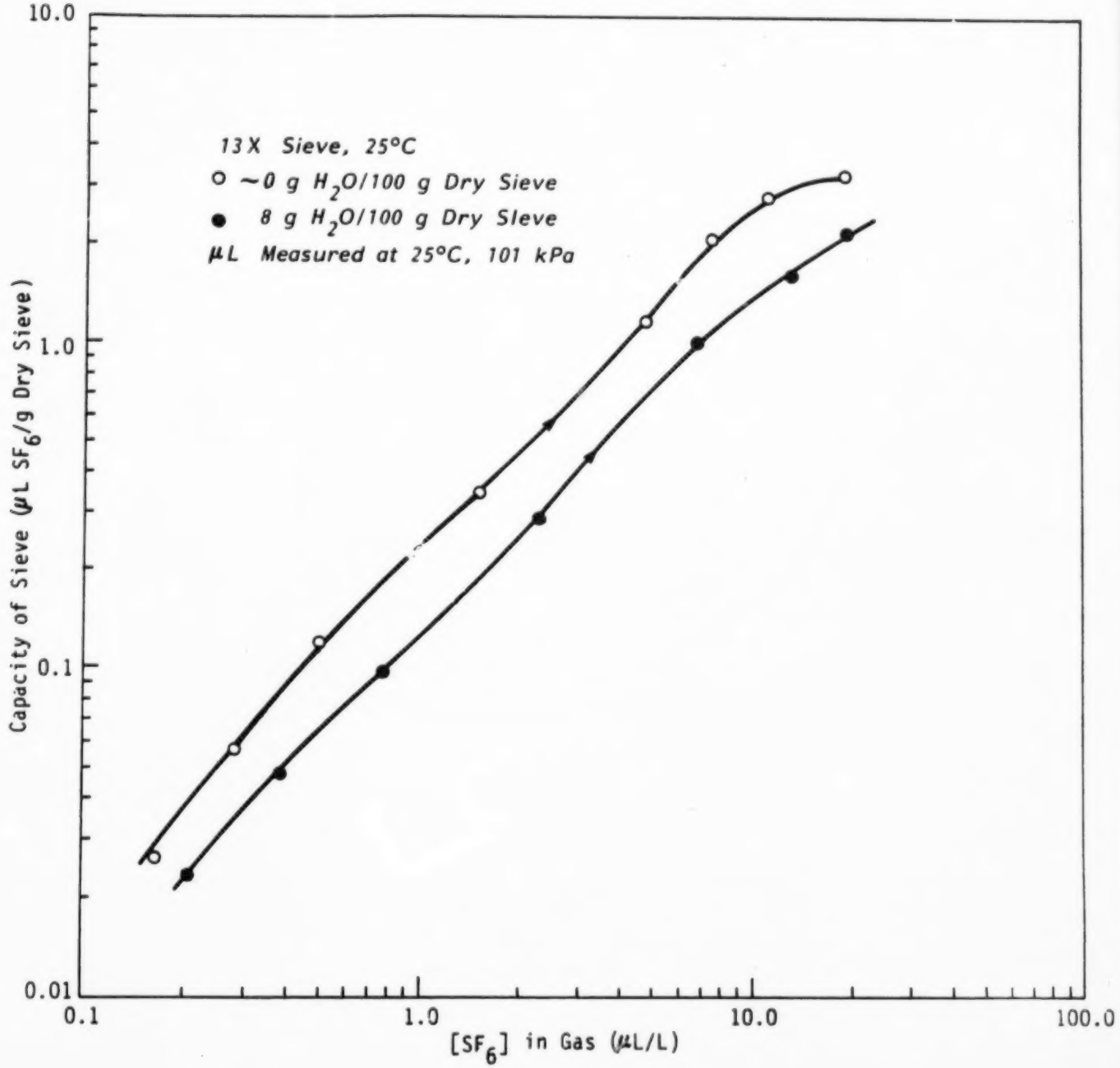

FIGURE C.1

ADSORPTION ISOTHERM FOR SF_6 ON LINDE 13X CYLINDRICAL PELLETS

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SF_6 on dry 13X sieve (effective pore size 9A) is 3.2 μL/g. This is an order of magnitude or more greater than for the AW500. Also shown in Figure C.1 is the adsorption isotherm if the sieve contains water. At a concentration of 8 g H_2O/100 g dry sieve a lower capacity of about 50% of the initial results. Increasing the water content of the sieve to 16 g H_2O/100 g (almost the full capacity of about 18 to 20 g H_2O/100 g sieve) resulted in no detectable adsorption. However, for a dry sieve, it is calculated that the time for saturating all the sieve in a dryer such as VDR5 with SF_6 would be less than three minutes. This indicates that intermittent injection would not be required to compensate for SF_6 adsorption on the dryer dessicant. However, about 20% of the SF_6 injected would be retained on the sieves if they are initially dry.

APPENDIX D*

Activation Products of He, SF_6, CH_4 and C_2H_4 in a Neutron Field

Assumptions

1. Neutron flux in the reactor vault ≈ 100% of thermal flux in core $\sim 10^{13}$ $n/cm^2/s$

2. Residence time in the vault ~24h = 24 x 3600s = 8.64×10^4 s

3. (1) and (2) give a neutron fluence $\sim 8.64 \times 10^{17}$ n/cm^2

4. Molar volume of all gases ~22.4L

A. ^4He does not produce any activation products. Ignore minuscule levels of ^3He in natural helium.

B. SF_6 at 5 μL/L; abundances: ^{32}S(94.5%) and ^{34}S(4.5%)

σ_γ : 0.53b/n and 0.23b/n

activation prod.: $^{33}S(\sigma_\gamma \approx 0b)$ and $^{35}S(\beta^-, t_{1/2} = 87.2d)$

- consider only ^{32}S giving ^{33}S, which will not yield any other act. product

- ^{35}S is 'stable' on the time scale of interest

#density of $^{32}S = 5 \times 10^{-6} \times 6.023 \times 10^{23} \times 1/22.4$ nuclides/$10^3 cm^3$

$= 1.34 \times 10^{17}$ nuclides/cm^3

#density of ^{33}S on activation of 1.34×10^{17} $^{32}S/cm^3$ in a fluence of 8.64×10^{17} n/cm^2 = 8.64×10^{17} $n/cm^2 \times 1.34 \times 10^{17}$ nuclides/$cm^3 \times 0.53 \times 10^{-24}$ cm^2/n = 6.2×10^{10} nuclides/cm^3

ie., 4.6×10^{-5}% of the original ^{32}S inventory becomes activated!

Similarly,

^{19}F(100%), $\sigma_\gamma = 9.6 \times 10^{-3}b$ to give ^{20}F ($\beta^-, t_{1/2}$ = 11s)

#density of ^{19}F = 6 x 5 x 10^{-6} x 6.023 x 10^{23} x 1/22.4 nuclides/$10^3 cm^3$

= 8.1 x 10^{17} nuclides/cm^3

#density of ^{20}F = 8.64 x 10^{17} n/cm^2 x 8.1 x 10^{17} nuclides/cm^3 x 9.6 x 10^{-27} cm^3/n = 6.7 x 10^9 nuclides/cm^3

ie., 8.3 x 10^{-7}% of the original ^{19}F inventory becomes activated!

Thus, SF_6 will give rise to no significant activated products due to short residence time and small n-cross sections.

C. The proposed introduction of 100 μL/L of CH_4, C_2H_4 will be small wrt the H_2O and CO_2 levels already present in the reactor vault air.

Overall Conclusion: These traces, at the proposed levels and short residence times, will not result in any significant activation product production.

*This analysis was carried out by G.F. Thomas, Associate Research Scientist, Combustion & Chemistry Unit.

APPENDIX E

Evaluation of Time for Steady State Concentration in Reactor Vault and the Steady State Concentration

An estimation of the time for the concentration (C,μL/L) of the vault (volume V litres) to reach a steady value when the vault exhaust rate is E(litres/sec) and the concentration and leakage rate from the sector under test are C_{inj} and L respectively is as follows. By a mass balance, assuming a background of tracer gas in all other leaking sectors of C_{BG} (=0 for SF_6, C_2H_4) gives:

$$V\delta C = LC_{inj}\,\delta t + (E-L)C_{BG}\delta t - CE\delta t$$

$$\frac{\delta C}{\delta t} = \frac{E}{V}\left(\frac{L}{E}C_{inj} - C\right) + \frac{E}{V}\left(1-\frac{L}{E}\right)C_{BG} \qquad (1)$$

Hence, at steady state, $\frac{\delta C}{\delta t} = 0$ giving the vault concentration C and the leakage rate L:

$$C = \frac{L}{E}C_{inj} + \left(1 - \frac{L}{E}\right)C_{BG} = \frac{L}{E}(C_{inj} - C_{BG}) + C_{BG} \qquad (2)$$

$$L = E\left[\frac{C-C_{BG}}{C_{inj}-C_{BG}}\right] \qquad (3)$$

ie. the higher the leakage rate L, the larger is the vault concentration C. Also, the lower the value of C which is accurately measurable, the lower is the injection concentration which may be used. For example, in the case of helium at a background concentration of 10 + 5 μL/L, an accurately measurable C is 50 μL/L. Hence, for a leak rate of 5% of the exhaust flow, C_{inj} should be about 1000 μL/L. A higher background would require higher values of C to be present to maintain accuracy and hence larger C_{inj}. Integrating equation 1 and substituting boundary conditions t=0, C=C_{BG} yields:

$$t = -\frac{V}{E}\ln\left[1 - \frac{E}{L}\left(\frac{C-C_{BG}}{C_{inj}-C_{BG}}\right)\right] \qquad (4)$$

This equation indicates that an infinite time is required to reach the steady state concentration given by equation 2. Assuming a 5% error in the measurement of $(C-C_{BG})$ gives from equation 2

$$C - C_{BG} = 0.95 \frac{L}{E} (C_{inj} - C_{BG})$$

which upon substitution into equation 4 gives

$$t = - \frac{V}{E} \ln 0.05 = 3 \frac{V}{E}$$

This equation indicates that the time to steady state is independent of the leakage rate and steady state is more rapidly attained if the reactor vault volume is small and the vault exhaust flow is large. (However, E cannot be too large since from equation 2, C may be too small to measure unless C_{inj} is also increased). For the NPD vault of volume 340 000 L and exhaust flow of 16 L/s, the time to "steady state" is 18 hours. This time may be reduced significantly if C_{inj} is large initially and then allowed to fall until the rate of rise of the vault concentration C begins to level out. At this point C_{inj} is maintained constant (see boiler room test). Otherwise, a reduction in the time to steady state may be obtained if the vault contains tracer gas at the start either from previous tests or through deliberate injection.

APPENDIX F

Estimation of Lowest Detectable Leakage Rate for Vault Cooling Room Test

An estimate of the lowest leakage rate that might be detected under the condition of the vault cooling room leakage test follows.

F.1 Vault Cooling Room to FM Room Leakage.

A mass balance over a time interval δt (minutes) is given by:

ethylene accumulation (Litres) in VCR of volume 255000 L = (ethylene injected into VCR) - (ethylene out with ventilation flow of 67800 L/min)

$$250000 \times 1^{-6}\ \delta C = 6.6 \times \delta t - C \times 67800 \times 10^{-6}\ \delta t$$

This equation assumes perfect mixing in the VCR and reduces to:

$$t = -3.76\ \ell n\left(\frac{97.35-C}{97.35}\right)$$

This equation is plotted in Figure F.1 for seventeen minutes at which time injection was stopped. After seventeen minutes, the ethylene concentration dropped due to ventilation loss and a similar mass balance yields:

$$t = -3.76\ \ell n\left(\frac{97.35}{C}\right)$$

This equation also plotted in Figure F.1 up to twenty-five minutes from the time of injection into the VCR at which time a sample of the gas was taken from the FM room.

The amount of ethylene entering the Fuelling Machine Room is given by the product of the VCR leakage rate(X), the time between the injection and sampling and the concentration of ethylene in the VCR. Graphical integration (Figure F.1) yields a value of 1614X. The result, if plug flow in the VCR is assumed is very similar. The increase in concentration in the FM room is therefore this product divided by the room volume (566 000 L) sine the FM room ventilation was zero. This increase must be less than 0.1 μL/L, the lower detection limit of the tubes. Hence, the leakage rate from the VCR to the FM room is calculated to be less

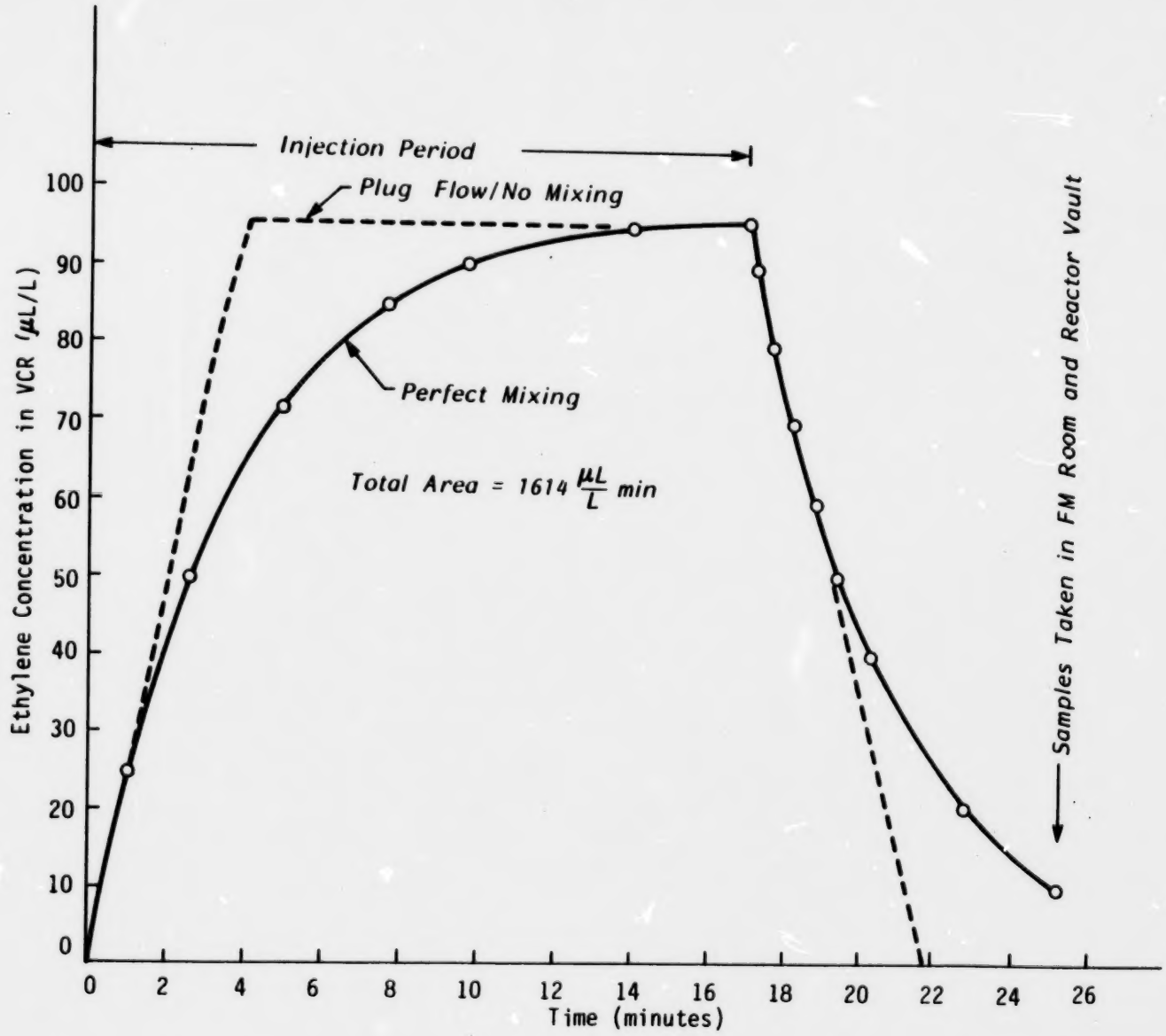

FIGURE F.1
CALCULATED VCR CONCENTRATION OF TRACER GAS

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than 0.6 L/s. It is recommended that the ethylene concentration for future tests be increased by a factor of ten to 1000 μL/L so that the lowest leakage rate detectable is decreased to less than 0.06 μL/s.

F.2 Vault Cooling Room to Reactor Vault Leakage

A mass balance over a time interval δt (minutes) when the concentration in the reactor vault increases by δC μL/L) as given by:

(ethylene accumulation) = (ethylene in due to) - (ethylene out due to)
(in vault 340 000 L) (leakage from VCR) (total adsorption on)
(mole sieve dryers;)
(flow = 21234 L/min)

$$340\,000\,\delta C = (L \times C_{VCR} - 21234\, C_{RV})\,\delta t$$

Solution of this equation gives the concentration C_{RV} at time t = 25 minutes when the vault was sampled. Noted that input from the FM room is negligible. The equation was solved on a computer by assuming a value of L and solving the C_{RV} with δt set to one minute and C_{VCR} given by Figure C.1. The solution was repeated with δt set to 0.25 minute when little change was noted. Other values of L were used until C_{RV} was 0.1 μL/L at 25 minutes from the start of injection. The value of L was found to be 0.8 L/s and it represents the lowest leakage rate detectable under the conditions of the test.

APPENDIX G

Estimation of Leakage Rate Through Motorized Valve MV22

G.1 SF_6 In-Flow to Vault Past MV22

As estimate of the leakage rate past MV22 based on a mass balance is as follows. Following the end of SF_6 injection, the SF_6 concentration in the vault fell due to exhaust flow at a rate of 0.4 μL/L per hour (Figure 3). It is assumed that the rate of SF_6 output due to the exhaust flow was similar at about 12:00 hours, the mid-point of the test. The accumulation of SF_6 in the vault is given by the slope of the curve during the SF_6 injection which from Figure 3 is 1.5 μL/L per hour. Hence, the SF_6 entering the vault is 1.9 μL/L per hour equivalent to 0.65 L/h ($\simeq 10$ cm^3/min) for the 340 000 L vault. This in-flow of SF_6 is equal to the leakage rate past the valve times the concentration of SF_6 at the injection area.

G.2 SF_6 Concentration at MV22

The concentration of SF_6 near valve MV22 is calculated as follows. At steady state, the loss of SF_6 due to diffusion along the 9000 cm^2 duct to the stack is equal to the SF_6 injection rate. Assume that the SF_6 concentration is constant on the valve side of the injection point (total distance = 25 cm) and falls linearly on the other side from a concentration C at the injection point to almost zero over a distance X. Hence, fifteen minutes after injection at 1000 cm^3 SF_6/min the average concentration over the distance X is given by:

$$15 \times 1000 = (C)(9000)(25) + \left(\frac{C+0}{2}\right)(X)(9000)$$

$$C = \left(\frac{15000}{9000}\right)/\left(25 + \frac{X}{2}\right)$$

By Fick's Law, ignoring bulk flow effects which are small, the loss of SF_6 due to diffusion is:

Duct Area x Diffusion Coefficient x Concentration Gradient = 9000 cm^2 x $\frac{0.15 \text{ cm}^2}{\text{sec}} \times \frac{(C-0)}{X} \times \frac{60 \text{ sec}}{\text{min}}$

This may be equated to 1000 cm^3/min, the SF_6 injection rate ignoring concentration build up at the injection area.

Hence,

$$(9000)(0.15)\left(\frac{1}{X}\right)\left(\frac{15000}{(9000)\left(\frac{X}{2}+25\right)}\right)(60) = 1000$$

giving X = 5 cm. This value of X is unreasonably small and could be a factor of 100 too low in the presence of turbulence. Hence, C = 0.006 (6000 μL/L).

G.3 Leakage Rate of MV22

From sections G.1 and G.2,

$$\text{Leakage Rate} \times 0.006 \frac{\text{cm}^3}{\text{cm}^3} = 0.65 \text{ L/h}$$

Hence, the leakage rate is 110 L/h or less than 0.1 L/s. This is insignificant compared to the total exhaust flow of 16 L/s.

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